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ANNOTATED BIBLIOGRAPHY OF VESSEL SIMULATION STUDIES  
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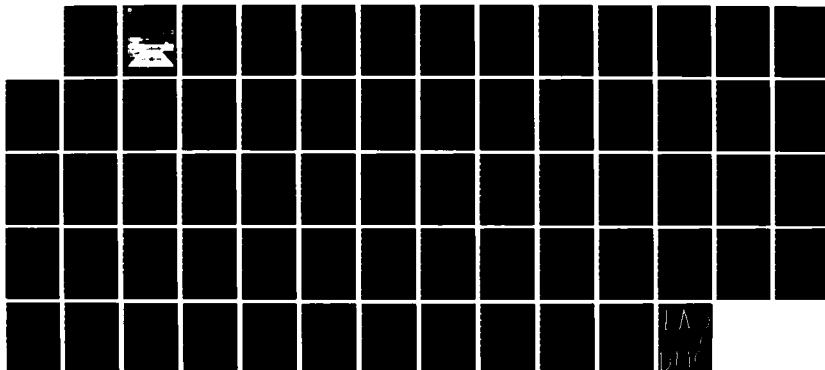
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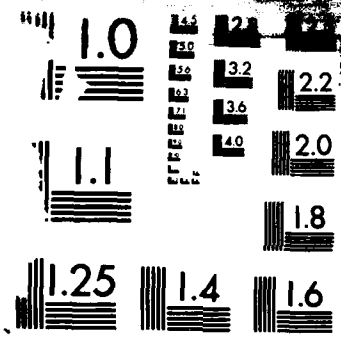
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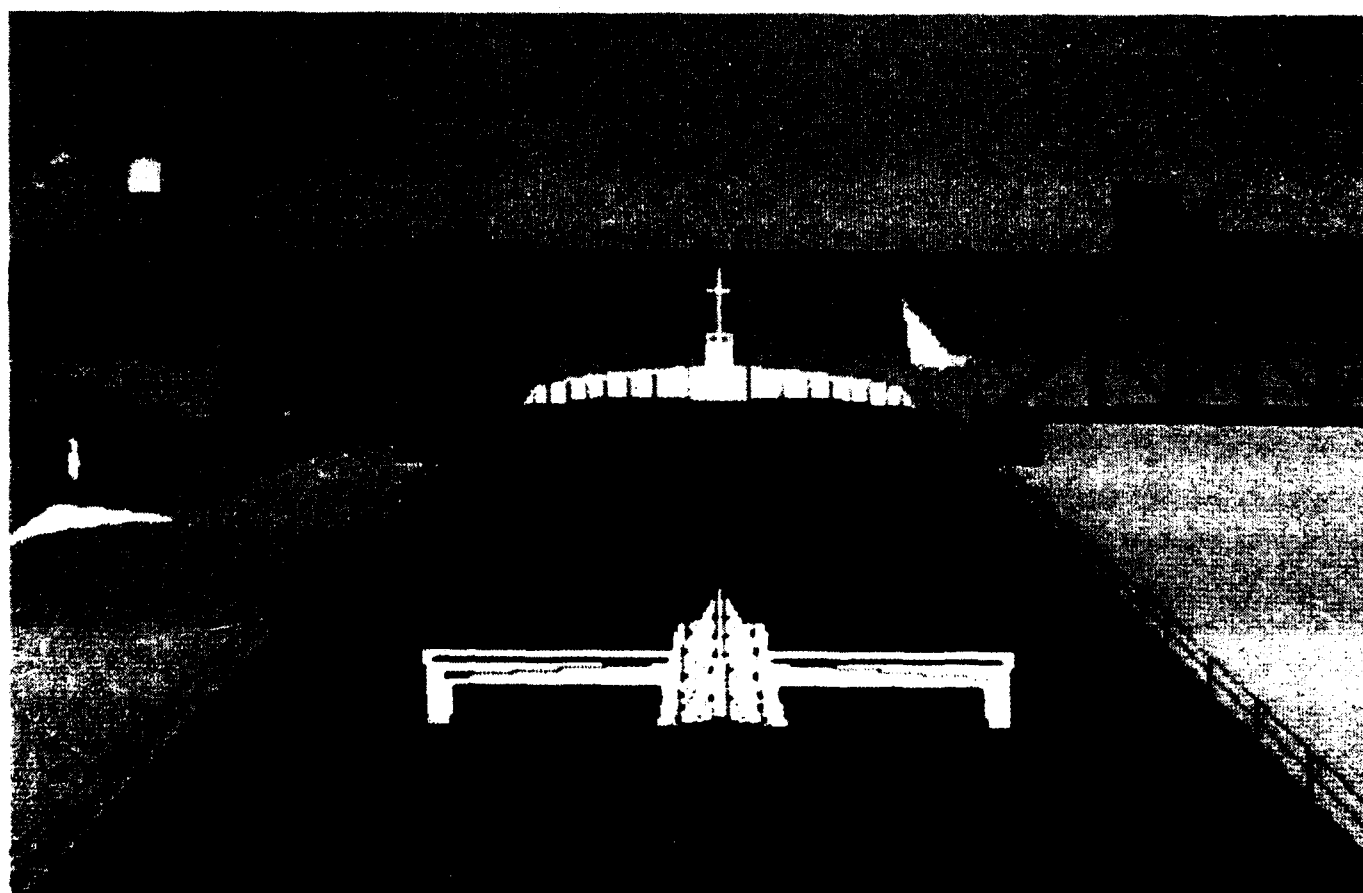
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# Annotated Bibliography of Vessel Simulation Studies Used in Channel Design

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report catalogs shiphandling simulation studies relating to channel design and/or modification. <i>Keywords:</i>		

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ANNOTATED BIBLIOGRAPHY OF VESSEL  
SIMULATION STUDIES USED IN  
CHANNEL DESIGN

Prepared by

Navigation Division  
Institute for Water Resources  
U.S. Army Water Resources Support Center  
Fort Belvoir, Virginia 22060-5586

For

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Washington, D.C. 20314-1000

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Report 86-R-1

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## PREFACE

The information contained in this report was collected while writing IWR rept. no. 86-R-2. This report is Report No. 86-R-2, Ship Simulator Capability and Channel Design. IWR Report 86-R-2.

No. 86-R-2 was authorized by Brigadier General Patrick Kelly, then Deputy

Director of Civil Works, to assess the shiphandling simulation capabilities of the U.S. Marine Administration, Army Corps of Engineers, and Coast Guard, MARAD, USACE, and USCG, as well as private facilities in the U.S. with respect to aiding the USACE in channel design and modification.

In the course of examining the vessel simulators, a brief annotated bibliography was compiled of each facility's channel design related reports. This bibliography provides citations and a brief description to 74 reports on → (to P. A) As such, it represents useful research in the area of potential real-world applications for simulation technology in cost effective harbor and waterway design. It was decided to supplement that initial survey of simulator literature with a more thorough search of published and unpublished sources including government manuals, research reports, proceedings of conferences, and the major water transportation and engineering journals. Our search emphasized U.S. publications as well as those studies concerned with the engineering rather than the human aspects of simulation research. The following report, while not exhaustive, is an attempt to catalog those shiphandling simulation studies that might be of use to Corps planners and engineers.

## ANNOTATIONS

1. Amdahl, Jorgen, and K. Harald Drager. 1981. Application of the Maneuvering Simulator, SALISIM, to the Analysis of a Grounding Incident. In Proceedings of the Second International Conference on Marine Simulation (MARSIM), Volume II, pp. A4-1--A4-20. Kings Point, NY: National Maritime Research Center.

The ship sailing simulator, SAILSIM, which has been developed for studying the maneuverability of ships and other floating structures under the influence of waves, wind, current, and limited depth is presented. This paper discusses simulation results which have been compared with full scale tests of the tanker "Esso-Osaka" showing reasonably good compliance.

The system has been applied to the analysis of a grounding incident with a 25,000 DWT tanker on the Norwegian Coast. The probable track of the tanker immediately before the grounding is studied steering the ship according to the log book.

The ability of the tanker to navigate the waterway, which among others consist of a narrow channel, is investigated varying the environmental conditions (current, wind) systematically. A steering procedure for the passage of the channel is proposed.

Despite some weakness with regard to the man-machine communication, it is concluded that the simulator has the potential of becoming a powerful tool in risk analysis of ship maneuvering.



2. Aranow, Philip I. 1982. Maneuvering Response Supplemental Experiments (Collier and Containerships). CAORF Report No. 42-8218-01. Kings Point, NY: National Maritime Research Center.
3. Aranow, P. and E. Wald. 1982. Comparison of the Impact on Piloting Performances of Extreme Wind Forces Under Variable Conditions of Ship Class and Stability, Channel Width, and Channel Bank Forces. CAORF Report No. 50-8011-02. Kings Point, NY: National Maritime Research Center.

The experiment examined the shiphandling performance of pilots transiting a narrow waterway under severe wind conditions and attempted to discern the variability in that performance which could be attributed to wind level and direction, ship class and stability, channel width, channel banks, as well as pilot background.

Three classes of vessels were used (two tankers and a LNG) and three levels of wind were employed, including conditions between 40 and 65 knots.

It was found that the pilots on the LNGs had significantly more difficulty than when the tankers were being conned. When transiting through a channel with vertical banks, less difficulties were encountered than with the same channel without banks. Differences in channel width affected the pilots on the LNG to a greater degree than those pilots who conned the tankers. Overall, the pilots were shown to be capable of

overcoming the wind-based instabilities and, therefore, differences in performance that were noted were due to other causes, such as ship characteristics. The LNG vessel was shown to have an exceptionally high level of directional stability at high wind levels.

4. Atkins, D. A., and W. R. Bertshe. 1980. Restricted Waterways Experiment IIIA Data Analysis and Findings. CAORF Report No. 24-7806-01. Kings Point, NY: National Maritime Research Center.

The objective of Experiment IIIA was to investigate effects of channel design, ship maneuverability, and aids to navigation configuration on the pilots' ability to navigate a narrow (500 ft wide) channel 5 nm long containing 3 turns.

The experiment consisted of transits of the simulated channel using the CAORF bridge simulator adjusted for an 80,000 DWT tanker. The experimental design reflected presence or absence of traffic, full or half normal rudder area and aid to navigation conditions including two buoy configurations, ranges, and precise navigator. Ship position, attitude data and ship control orders were collected during each transit. Conclusions included evaluation of success in transiting the channel, variance in cross track position effect of traffic ships, and an evaluation of ship control orders.

Conclusions from static position estimation trials include evaluation of position estimation accuracy and statistics on the accuracy of bearing estimation related to actual bearing angle.

The report also deals with the ability of CAORF to simulate navigation ranges.

5. Barr, R. A., E. R. Miller, F. C. Lee, V. Ankudinov, and P. Van Dyke. 1981.

Maneuvering of Tankers at Deep Water Ports. Report No.

DOT-CG-945927-A. Washington, DC: U.S. Department of Transportation,  
U.S. Coast Guard.

The ability of tankers from 87,000 to 400,000 DWT to safely operate and maneuver at a multi-SPM deep water port (LOOP) under typical wind, waves and current conditions for the port, was studied using simulations of definitive maneuvers and coursekeeping, autopilot controlled simulations of port arrival and departure maneuvers and hands-on, real time simulations of port arrivals and departures by licensed pilots. All ships could operate successfully in a design environment (26 knot wind, 1.5 knot current and 10 foot waves), although the performance of the 87,000 DWT ship is marginal. The particular course chosen for SPM approaches may have a significant effect on safety in the event of a ship casualty.

6. Broekhaven, L. M. J. B. Malherbe, P. Kerckaert, T. Elzinga, and J. Perdok.

1984. A Comparison Between Simulator and In-Situ Maneuvers of  
Container Ships Calling at the Port of Zeebrugge. In Proceedings of  
the Third International Conference on Marine Simulation (MARSIM), pp.  
259-270. Rotterdam, The Netherlands: Maritime Research Institute  
Netherlands.

For the extension of the Port of Zeebrugge, Belgium, several nautical studies were executed on the ship handling simulators at the Marine Research Institute Netherlands (MARIN). In the original situation of the port and in one particular construction phase a number of in-situ measurements on board of container vessels were carried out. This paper deals with a comparison between the in-situ and simulator maneuvers in similar conditions and discusses the face, content and predictive validity of the simulators used.

7. Committee to Assess CAORF, Marine Board, Commission on Engineering and Technical System, and National Research Council. Report of the Committee to Assess the Computer Aided Operations Research Facility (CAORF). 1983. Washington, D.C.; National Academy of Sciences.

The physical facility, research program, government-contractor management structure, and other features of the Computer Aided Operations Research Facility (CAORF) of the U.S. Maritime Administration are evaluated, and suggestions offered for improvement and alternative arrangements.

8. Conway, Jane A. 1985. An evaluation of the Effect of a Bridge-Tunnel Configuration on Channel Navigability. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development. pp. B3-1 -- B3-18. Kings Point, NY: National Maritime Research Center.

This study utilized the Computer Aided Operations Research Facility (CAORF) simulator to investigate the effect of the proposed I-664 bridge tunnel causeway on the navigability of Newport News Channel. The ability of docking masters to successfully undock a 150,000 DWT dry bulk collier and pilot her through the Channel entrance was evaluated. The CAORF model of the channel included several modifications to the existing channel design, as well as the placement of the bridge tunnel and accompanying structures within the channel. Based on previous CAORF research, four areas were identified as problematic to shiphandling. Initial data analysis shows that the influence of the bridge tunnel configuration may cause other areas to be difficult to navigate. Upon completion of the study, further data analysis will determine to what extent the bridge tunnel configuration will influence overall navigability.

9. Cook, R. C. 1980. Investigation of Large Tanker Transits of a Proposed Deepwater Channel Into the Port of Corpus Christi, Texas. CAORF Report No. 24-8012-01. Kings Point, NY: National Maritime Research Center.

The Nueces County Navigation District No. 1 proposes to widen and deepen the existing entrance channel through Aransas Pass to accommodate VLCC and other large vessel traffic. The Maritime Administration's Computer Aided Operations Research Center (COARF) was used to investigate the adequacy of the proposed improvements and the impact of alternative docking basin designs on transits of 250,000 DWT tankers under adverse environmental conditions.

10. Cook, R. C., and W. R. Bertshe. 1979. Investigation of Limiting Channel Conditions for LNG Vessel Transit into the Port of Pascagoula, Mississippi. CAORF Report No. 24-7914-01. Kings Point, NY: National Maritime Research Center.

The port of Pascagoula, Mississippi has been proposed as a site for a liquefied natural gas (LNG) ship unloading and transfer facility. This report details the completed investigation, performed through simulation experiments, which indicates the viability of the existing Pascagoula Harbor channel system for LNG vessel transit. Specific limiting factors investigated were: wind, wind and current, turns, bank effects, and tug forces. Channel improvements to the port are suggested. On-line investigation is also recommended to incorporate the human factor into the port evaluation process.

11. Dallinga, R. P., Th. Elzinga, and R. H. M. Huijsmans. 1986. Ship Simulation Models: An Aid to Harbor Design. Journal of Waterway, Port, Coastal and Ocean Engineering. 112: 255-268.

In the design and development of ports, cost-benefit analyses are often used to select the final design. These analyses show on the one hand the costs, i.e., capital and maintenance costs for dredging and investment costs, and on the other hand the benefits of a larger transport volume. The economy of a port is substantially influenced by the dimensions of approach channels and port entrances. To determine optimal

dimensions of a harbor, the vessels that will call at the port have to be considered, because the channel and port dimensions are largely influenced by the behavior of the vessels. In the prediction of ship motions, simulation techniques have proven to be adequate tools. Two such simulation techniques are discussed: one related to horizontal ship motions; the other related to vertical ship motions.

12. D'Amico, Anita D. 1985. Determination of the Optimal Channel Design for the Gaillard Cut of the Panama Canal. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development, pp. B6-1 -- B6-23. Kings Point, NY: National Maritime Research Center.

The Panama Canal Commission (PCC) is considering redesigning the Gaillard Cut of the Panama Canal to permit safe meetings between Panamax-size vessels. The objective of the Cut Widening Study is to determine the specific dimensions of the optimum navigation channel which will afford a balance between excavation costs and safety. To systematically evaluate the relative safety of various channel configurations, the PCC decided to utilize a combination of fast-time and real-time simulation as the primary method of assessment. This method uses fast-time simulation to compare the relative safety of numerous channel layouts in combination with numerous operational conditions. The result of the fast-time analysis is a set of candidate solutions which the PCC can evaluate in light of the excavation requirements and operational conditions of each candidate channel design. The "best" solution will be the channel configuration and the accompanying operational conditions

which afford an acceptable level of safety with the least excavation and maintenance costs. The recommended channel design will then be subjected to real-time simulation analysis during which PCC pilots will be required to conn a Panamax-size vessel past another Panamax through the improved Gaillard Cut. Only if this last simulation analysis yields results which indicate that such meetings could occur safely within the new design dimensions of the channel will the new channel design be deemed acceptable.

13. D'Amico, Anita D. 1984. Validity Issues in Marine Simulation Research. Paper presented, Society for Computer Simulation Conference.

This paper dicusses some validity issues from the viewpoint of a human factors psychologist. The emphasis is on validity related to the human being in the loop, rather than on the hydrodynamic or engineering evaluation which would compare ownship to full scale performance.

14. Dey, D., U. Hohage, and M. Schmidt. 1981. Models for Shiphandling Simulators. In Proceedings of the Second International Conference on Marine Simulation (MARSIM), Volume II, pp. A7-1 -- A7-19. Kings Point, NY: National Maritime Research Center.

This paper discusses the mathematical model as an important module of a marine simulator. The required capabilities of the model have to be derived from the simulation aims; this is a challenging task for the potential simulator user.



The simulator must operate in the entire maneuvering region of a ship, requiring a complete simulation of all relevant ship systems and maneuvering influences. The shortage of usable data and information for the described purpose can be overcome by using a modular structure of the entire model with submodules defined on a physical basis and effects sometimes incorporated phenomenologically.

Such a model should have a flexibility and adaptability which allows the incorporation of all available present and future information. Using this philosophy a valid model for simulator training and man-machine studies is achieved.

15. Dickey, Dean E. and Ron K. Gress. 1986. Ft. Madison Bridge Study.

Report No. CG-W-01-86. Washington, DC: U.S. Department of Transportation, U.S. Coast Guard.

This report is a project summary describing the preparation and conduct of a simulator experiment in river tow navigation through the Atchison Topeka and Santa Fe R.R. Bridge at Fort Madison, Iowa using the Coast Guard Maneuvering Simulator. Detailed qualitative and quantitative results obtained from the simulations are presented and analyzed. The study was designed to determine the effects of different levels of current, horsepower, and alternate channel design as well as pilot performance on safety at the bridge. This study was initiated by the Second Coast Guard District due to concern because of a number of accidents at the Ft. Madison Bridge.

16. Eda, Haruzo. 1979. Development and Verification of Mathematical Models for Shiphandling Simulators. In Proceedings, Third Annual CAORF Symposium, Maritime Simulation Research, pp. 18-1 -- 18-10. Kings Point, NY: National Maritime Research Center.

An effort has been made to develop maneuvering motion prediction capability (i.e., digital-computer simulation capability) of real ships proceeding under various conditions with changes in ship loading and water depth. This paper presents the results of maneuvering characteristics and ship trajectories predicted through computer-aided analysis and utilizing the model test results. Also included are the correlations between predictions and trial results. In an effort to improve the mathematical model, which represents ship maneuvering motion under actual operating conditions, vessel tracking measurements were made on a 80,000 DWT tanker during transit in New York Harbor waterways. Application of these results has been made to a variety of harbor configurations from the viewpoint of maneuvering safety during harbor transit.

17. Elzinga, Th., and M. P. Bogaerts. 1984. A Simulator Study for LNG Transport by Gas Carriers to Elmhaven, The Netherlands. In Proceedings of the Third International Conference on Marine Simulation (MARSIM), pp. 249-258. Rotterdam, The Netherlands: Maritime Research Institute Netherlands.

In order to guarantee a safe transport of Liquefied Natural Gas (LNG) by gas carriers of 1,250,000 m<sup>3</sup> to Eemshaven, detailed studies were carried out on the simulator at MARIN. The aims of the studies were to determine horizontal dimensions of the approach route, access channels and harbor entrance and to determine limiting operation conditions. A detailed mathematical model was developed, based on extensive model tests, including effects of shallow water, banks, environmental conditions, tugs and bow thruster. Also the application of an advanced electronic position information system was evaluated on its nautical merits. The approach route, several port entrance lay-outs and emergency maneuvers were investigated.

18. Elzinga, Th., and W. G. Borst. 1983. Simulation Models for Ports in Developing Countries. In Proceedings of International Conference on Coastal and Ports Engineering in Developing Countries, pp. 632-644. Colombo, Sri Lanka: International Conference on Coastal and Port Engineering in Developing Countries.

The use of simulation models with respect to port developments is elucidated. Especially the application of a ship handling and maneuvering simulator is illustrated by a case study concerning a port development in a developing country. Finally the significance of simulators with regard to port developments and port operations are presented.

19. Engineering Computer Optecnomics, Inc. 1986. The Captains System.

Annapolis, MD: Engineering Computer Optecnomics, Inc.

This paper describes the Captains System ship simulator, recently developed by Engineering Computer Optecnomics, Inc. Networked microcomputers are used to generate a three channel visual scene and an extensive ship maneuvering model.

20. Gardenier, John S. and Larry L. Daggett. 1985. River Tow Needs for Maneuvering Room on the Upper Mississippi River. Report No.

CG-D-24-84. Washington, DC: Marine Technology Division Office of Research and Development, U.S. Coast Guard.

This report is a project summary describing the preparation and conduct of a simulator experiment in tow maneuvering on the Upper Mississippi River. The experiment was designed to determine whether substantial risk reduction benefits could be achieved with some amount of additional maintenance dredging in the Upper Mississippi River. It was stimulated by concern that safety would decrease with a change in dredging policy that would effectively reduce the channel dimensions.

The study was limited to a single 4.5 mile area below Wabasha, Minnesota, from mile 755.5 to 760 in low water, high flow rate conditions. Two river pilots each made twenty runs under various controlling channel dimensions: widths of 300 feet versus 400 feet and depths of 11 feet versus 13 feet.

The findings clearly indicate that substantial reductions of grounding risk would result from maintaining the channel at not less than 400 foot width in bends. For the river area examined, this would require relatively modest increases in dredging, and would not require any changes in dredging regulations.

21. Gilder, M., A. D'Amico, K. E. Williams, W. Korosk, and S. Schilling.

1982. Investigation of the Effects of Ship's Speed and Directional Stability on Vessel Control in Restricted Waterways. CAORF Report No. 42-8118-01. Kings Point, NY: National Maritime Research Center.

This report describes a U.S. Coast Guard sponsored investigation of the effects of ship' speed in restricted waterways performed at the Computer Aided Operations Facility (CAORF). This task was designed to determine how a vessel's risk of collision with another ship varied as a function of ship's speed and according to the initial separation of collision in terms of critical ranges between ships, the types of rudder deflection a pilot must be concerned with and the duration of time that the possibility of collision exists. The report graphically shows a set of turn circles for rudder deflections from 5° to 35° for both directionally stable and unstable vessels at 4, 7, and 10 knots.

22. Ginsberg, Lanny D., and William C. Miller. 1986. An Evaluation of the Navigability of the Mississippi River Gulf Outlet Under Two-Way Traffic Conditions Using CAORF Simulation Technology. Prepared for U.S. Army Corps of Engineers, New Orleans District. Kings Point, NY: Computer Aided Operations Research Facility.

This report details a study performed for the New Orleans District Corps of Engineers and the Port of New Orleans Board of Commissioners to determine the feasibility of allowing large ships to pass in the Mississippi River Gulf Outlet (MRGO). The study was conducted at the U.S. Maritime Administration's Computer Aided Operations Research Facility (CAORF). Three scenarios were developed to assess the feasibility of two-way traffic in the MRGO involving 26,000 DWT SL18's. The scenarios differed with respect to the visibility afforded the pilot. The three conditions were unlimited visibility, daytime; limited visibility, daytime, and unlimited visibility, nighttime. Each pilot made two transits under each scenario condition. Included in the study was a proposed aids to navigation design which the United States Coast Guard, along with the pilots, believed represents an improvement over the existing aids. The results indicated that current restrictions on passing under nighttime conditions and limited visibility conditions should be maintained. However, in the unlimited visibility, daytime condition, pilots' performance improved after adjusting to the simulator and the proposed aids to navigation design.

23. Graff, J. and P. F. Dement. 1984. Aids for the Design of Harbor Structures and Training of Ship Captains and Pilots. In Proceedings of the Third International Conference on Marine Simulation, pp. 227-238. Rotterdam, The Netherlands: Maritime Research Institute Netherlands.

This paper presents the facilities which were used with success during a study carried out by Sogreah in collaboration with the port of Le Havre Authority (PLHA) for the Kwang Yang Project in South Korea and presents the latest developments in training facilities at Port Revel.

24. Hatton, Robert, Vladimir Ankudinov, and Roderick Barr. 1984. Model Tests and Computer Simulations of a 15-Barge Tow for the Upper Mississippi River. Report No. CG-D-10-84. Washington, DC: U.S. Coast Guard.

A maneuvering model was developed, for a typical river tow, with experimentally determined hydrodynamic coefficients.

The investigation included extensive model tests in both deep and shallow water, development of a method for predicting tow hydrodynamic coefficients, and simulations of tow behavior as a function of channel dimensions and potential obstacles to navigation.

25. Huval, Carl. 1985. Ship Navigation Simulator Study Upper Mobile Bay Channel. Department of the Army Miscellaneous Paper No. HL-85-7. Vicksburg, MS: Waterways Experiment Station, Corps of Engineers.

Mobile Harbor navigation channel presently can accommodate ship drafts up to the authorized channel depth of 40 ft, depending on tide levels, dredging overdraft amount, and rate of channel shoaling. Many of the larger dry bulk carriers, such as coal colliers, are entering or leaving Mobile Harbor in a light loaded condition. This makes the movement of cargo more expensive and lowers transportation efficiency that could be possible by fully utilizing the larger vessels and their economies of scale.

The relatively narrow channel width of 400 ft causes navigation problems, especially in the upper Mobile Bay channel reach where overbank depths become very small. In addition, ship steering problems have been reported by pilots in the vicinity of the Arlington Channel and when meeting a docked ship at the McDuffie Island Coal Terminal. Mobile District is considering a plan to deepen and widen the Mobile Harbor navigation channel in phases to ultimately provide a 55- by 650-ft channel.

The presently authorized Mobile Harbor Navigation Project does not include a turning basin in the lower part of Mobile River or the upper part of Mobile Bay. There is no provision for a safe anchorage area for deep-draft vessels while awaiting berths. A turning basin and an anchorage area in the upper bay region has been proposed by the District.



This report presents the results of a navigation study conducted on the U.S. Army Engineer Waterways Experiment Station (WES) Ship Simulator. The purpose of the study was to investigate navigation improvements due to channel widening in the upper bay area. The impact of the proposed anchorage area and turning basin was also investigated. The effect of channel depth increases on navigation conditions was investigated separately, and was not considered in this study.

As part of the investigation a reconnaissance trip aboard a typical bulk carrier was conducted to observe pilot maneuvers and to record the inbound ship transit with video tape equipment and still photographs. Special tests were conducted on the Mobile Bay scale model to record current patterns in the upper bay study region. The study area navigation channel was schematized on the simulator using available navigation charts and topographic maps, and the District furnished hydrographic survey data. Ebb tide current data from the physical model were used to give realistic inbound test conditions on the simulator. The simulator visual scene was created using the data recorded during the inbound ship transit, maps, and charts.

The study showed that careful pilot control was required to maneuver the simulator ship in the 400-ft-wide channel in the upper bay reach. Anticipating the ship response at the Arlington Channel and the docked ship was necessary to prevent ship grounding or collision. The 650-ft-widened channel, the anchorage area, the the turning basin increase the safety margin in the upper bay reach by greatly decreasing the

bank-suction forces at Arlington Channel and the docked ship. The proposed project will provide greatly improved navigation conditions in the upper bay.

26. Huval, Carl, Bradley Comes, and Robert T. Garner III. 1985. Ship's Simulation Study of John F. Baldwin (Phase II) Navigation Channel San Francisco Bay, California. Department of the Army Technical Report No. HL-85-4. Vicksburg, MS: Waterways Experiment Station, Corps of Engineers.

The WES Research Ship Simulator was used to evaluate the design of Phase II of the John F. Baldwin Ship Channel and to study the impact of the deepened channel on the navigability of large tankers inbound to the Long Wharf docking facility near Richmond Harbor. The present channel and maneuvering area is 35 ft deep and is inadequate for the larger tankers bringing crude oil from the Alaskan North Slope. The San Francisco District has proposed to deepen the channel to 45 ft deep. The authorized 35-ft-deep channel was simulated to verify the ship simulator setup as well as establish the base maneuvering strategies, and the proposed 45-ft-deep channel was simulated to study the proposed conditions. In addition to the tankers, containerships navigating into Richmond Harbor entrance channel were also simulated to investigate the impact of channel deepening on other ships using the maneuvering area.

The proposed project will allow fully laden 87,000-DWT and partially laden 150,000-DWT tankers to unload at the Long Wharf. Present tanker operations require all but the smallest tankers to anchor in the main bay

and off-load a substantial part of the cargo into shallower draft tankers that can be accommodated with the 35-ft-deep channel. The proposed channel will reduce transportation costs as well as reduce the possibility of oil spills in San Francisco Bay.

As a part of the project, a reconnaissance trip was made to observe ship and pilot operations and to record the inbound trip into the Long Wharf maneuvering area on a typical tanker presently using the channel. The channel geometry, the overbank depths, and the visual scene were then developed for the simulator using maps and photographs of the project area. All important visual information was included so as to provide the proper visual cues to the pilot conning the ship. Special tests were conducted on the San Francisco Bay-Delta Model to gather realistic tidal current data for input into the ship simulator. All simulations were run with a 20-knot wind blowing from the southwest.

Test results indicate that it is very important to reduce tanker speed in Southhampton Channel for inbound transits to about 5 knots before starting the large right turn into the maneuvering area. Acceptable docking postures can be achieved for both existing and proposed channel conditions under both ebb and flood tide so as to allow safe tanker docking into the Long Wharf. The containership tests indicate that it is reasonably safe to maneuver around the point and line up with the Richmond Harbor entrance channel on flood tide. Ebb tide conditions require very careful control of ship speed and position to execute a safe turn in the maneuvering area when piloting the 810-ft containership. The 638-ft containership was much easier to maneuver around the point.

27. Hwang, Wei-Yuan. 1985. The Validation of a Navigator Model for Use in Computer Aided Channel Design. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development, pp. A5-1 -- A5-17. Kings Point, NY: National Maritime Research Center.

Real-time simulator test data were used to validate the CAORF autopilot. The autopilot is designed to steer ships in a channel in the presence of passing ships. Important piloting behaviors were identified based on the observed data. The validated autopilot is able to navigate the ship to a performance level similar to human pilots. Based on the common behavior of the test subjects, the autopilot was adjusted to represent a typical pilot. It was found that the representative autopilot is consistent in performance, but human pilots are more flexible because of their adaptability to the environment, the situation, and the ship they control.

28. Hwang, Wei-Yuan, Jack C. Schryver, and William C. Miller. 1986. Norfolk-Sealanes Compressed-Time Simulation Study. CAORF Report No. 20-8305-01. Prepared for U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: Computer Aided Operations Research Facility.

Time-domain off-line simulation was carried out for a 915-foot long 150,000 DWT collier transiting in the Atlantic Ocean Channel which provides access to Chesapeake Bay and Hampton Roads; an autopilot was used to steer the ship. Constant wind and current and long crest random waves

were modeled as the environmental disturbances to ship motions; one sample function of wave activities was used for each different sea state. Horizontal motions were examined to characterize the level of difficulty involved in maintaining the ship in the channel. Vertical motions were examined to project the depth of penetration and frequency of bottom contact. Frequency-domain analysis was conducted to complement the findings from the time-domain simulation. It was found that only the portside bottom was threatened by bottom contact, which mainly occurred with waves of lower peak frequency. Increasing water depth reduced bottom contact, but increased the difficulty of keeping the ship in the channel. A table is provided of different channel layouts required by different wave conditions. When the layouts are used in combination with wave statistics, a channel layout can be designed based on desired operational level.

29. Hwang, Wei-Yuan, and Edmund J. Kaufman. 1986. Validation of Ship Operator Model for Computer Aided Canal and Channel Design. CAORF Report No. 96-8416-02. Prepared for Panama Canal Commission, Balboa, Panama. Kings Point, NY: Computer Aided Operations Research Facility.

This study was performed as part of the development effort for the Panama Canal Gaillard Cut Widening Study. In this project, possible channel designs were screened out by means of fast-time computer model of shiphandling. To employ this model effectively, a control module, or autopilot, was developed to execute shiphandling decisions in a manner

similar to that of a human pilot. These decisions had to be properly executed aboard two ship types: the Series 60 "Validation Ship", and the Panamax bulk carrier.

Data from seven PCC pilots was collected via the full-fidelity simulator, and important performance parameters extracted for the validation vessel. By manipulating the values for these parameters, it was found that the performance of individual pilots could be approximated with the autopilot. A "representative" autopilot was constructed by using values most commonly exhibited by the PCC pilots for each parameter.

Only very limited human pilot data was collected for the Panamax ship because meetings between Panamax vessels on the Gaillard Cut are not within the realm of the pilots' experience. In general, the parameter values used for the validation vessel were used for the Panamax autopilot as well, based on the fact that the autopilot was intended to be non-dimensional. Only in the event that clear differences between piloting the validation vessel and piloting the Panamax were exhibited by the PCC pilot was the autopilot modified.

30. Jones, K. 1980. Analysis of Simulated Groundings in Valdez Narrows.

CAORF Report No. 17-7803-01. Kings Point, NY: National Maritime Research Center.

This report describes a study that examined the behavior of masters of simulated large tankers that suffered credible failures of propulsion or steering during transits of a steep-walled channel with a large rock midway across the passage. The data on which the study was based were derived from a research experiment and several operational exercises that were performed on the Computer Aided Operations Research Facility (CAORF).

The transits conducted on the CAORF Simulator involved passages under various conditions of initial speed, visibility, and wind conditions. Test data were analyzed from recorded ground tracks.

The conclusions reached suggest that, provided the maximum ship speed is limited, recovery from even critical failures may be achieved by the use of tugs.

31. Kaufman, Edmund J. 1985. Optimizing the Use of Compressed Time

Simulation as a Screening Device for Alternative Channel Layouts. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development, pp. C1-1 -- C1-8. Kings Point, NY: National Maritime Research Center.

This paper describes a project which is currently being performed in support of the Panama Canal Widening Study. In this project, fast-time computer simulation is being used to select the design for a waterway improvement from among a great many layout alternatives. Even given speed advantage of fast-time simulation over real-time simulation, there are still too many alternatives to permit each one to be tested directly.

Therefore, a decision strategy has been devised which will permit the systematic elimination of most of the alternatives based on the results of directly testing a small sample.

In this strategy, conditions which need to be taken into consideration are broken down into operational conditions of the vessel, and layout conditions of the channel. These are rank ordered according to effectiveness and economy, respectively. Test runs are done, each run comprising one set of operational conditions and one layout alternative, and the results of these runs compared to an established safety criterion. When a run passes the safety criterion, all less economical layout alternatives are eliminated from consideration for the operational conditions being used. When a run fails the criterion, all less effective sets of operational conditions are eliminated for the layout being used. In this way, a subset of layout alternatives are identified and the level of operational effectiveness necessary for safe passage is identified for each. The sponsor then chooses one alternative which can be directly implemented, or tested further using on-line simulation.

32. Knierim, Thomas J., and Harry C. Breitenfeld. 1977. Validation of CAORF Ships and Scene. In Proceedings, First Annual CAORF Symposium. pp. 49-53. King's Point, NY: National Maritime Research Center.

Visual testings and ground tracks resulting from several experiments show that CAORF reacts realistically in both deep and shallow water. The visual scene and ship-handling characteristics are so realistic, the



man-in-the-loop reacts to the CAORF experience with all the anxieties, desires, and frustrations he would normally experience aboard ship. As the navigator at sea strives for an incident-free voyage, the navigator at CAORF does the same. He can literally "sweat" through the more difficult problems. Consequently, pilots often look forward to being relieved after spending hours on the CAORF bridge. It is this kind of real world response that is essential to achieving a meaningful measure of his performance.

33. McCallum, Ian R. 1984. "Which Model?" A Critical Survey of Ship Simulator Mathematical Models. In Proceedings of the Third International Conference on Marine Simulation, pp. 375-388. Rotterdam, The Netherlands: Maritime Research Institute Netherlands.

All ship simulators incorporate one or more mathematical models of the ship. Little attention has to date been focused on the requirements of these models. This paper examines three types of ship maneuvering models, using the Cardiff Ship Simulator, in a port evaluation study. It is concluded that for most simulation tasks it is fully feasible to use mathematical models which can be produced relatively cheaply and quickly.

34. McCallum, Ian. 1986. Port Design and Ship Operational Studies Using Microcomputer Based Simulation Aids. In The Dock and Harbour Authority, pp. 34-37. London, England: Foxlow Publications, Ltd.

This article discusses the economic benefits of using the DYNATRACK offline microcomputer ship simulator to refine channel designs. The

author cites Australian applications involving 50,000, 120,000, and 200,000 DWT vessels at various harbors. He also discusses the economy and high fidelity of the MARDYN Port Design Simulator used by the Belgian Consulting Engineers, Haecon NV, for container ships at the port of Antwerp. Also mentioned is a fully modular model which is compatible to MARDYN and DYNATRACK. Finally the author promotes the transportability of the actual simulators.

35. McDonald, George T. 1985. Mobile Harbor, Alabama: A Pragmatic Approach to the Determination of an Acceptable Channel Design. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development, pp. B5-1 -- B5-7. Kings Point, NY: National Maritime Research Center.

The purpose of this paper is to present a synoptic view of the process by which the Mobile Harbor, Alabama channel limits are being determined. The process described herein takes place in a national political and economic climate which dictates that the most efficient project be developed and that a greater share of project costs be assumed by the sponsoring non-Federal interest. The key elements to consider, therefore, are those variables which affect efficiency and costs. In the case of deep-draft navigation projects, the basic factor of cost is quantity of material to be dredged which is directly related to channel width and depth of a proposed project. Other factors may affect cost, such as side slopes, method of disposal, distance to disposal areas, etc., but these are generally implicit in unit cost to dredge and are used as a multiplier of quantity of material to determine total project costs. The second

element of efficiency is project benefits. Benefits, expressed in terms of transportation savings, reduced delays, and reduced vessel damages, must exceed costs for a particular channel width to be favorably considered. Benefits are based on existing and projected commodity movements in those vessels which would use a given depth of channel. The problem, therefore, is to obtain the lowest project costs by reducing dredging quantities resulting from decreasing channel widths while at the same time providing a commensurate level of benefits which would have accrued to the original project design had it been constructed. The process described herein demonstrates the resolution of this problem in the case of the Mobile Harbor, Alabama project.

36. McIlroy, William. 1982. Background and Review of Ship maneuvering Response Experiments. CAORF Report No. 42-82110-01. Kings Point, NY: National Maritime Research Center.

This report discusses the background of a number of research projects in the area of pilot controllability and ship maneuvering response performed at CAORF, and reviews some of the important conclusions. These experiments evaluated the human/ship performance in relation to available navaids, on board electronic aids, provision for wheelhouse information, ship characteristics, availability of tug assistance and environmental factors. Some observations are made on the occurrence of groundings and their relationship to ship characteristics and human capabilities.

37. McIlroy, William. 1982. Tug Usage for Control and Deceleration in Restricted Waterways. CAORF Report No. 42-8009-02. Kings Point, NY: Computer Aided Operations Research Facility.

The investigations described in this report form the first part of a series of experiments planned at the Computer Aided Operations Research Facility (CAORF) to investigate the effectiveness of tugs in restricted waterways and the variability in pilot operating procedures. The present experiment involved comparisons between harbor pilots and docking masters, ship size (80,000 DWT and 250,000 DWT tankers), tug number, tug power, and tug availability. A simple harbor scenario involving straight legs (3/4 nm in length and 800 feet wide) and a widened 45° turn was used. The water/depth ratio was 1:15. The ships experienced a northwesterly wind fluctuating around 30 knots and a flood current of 1 knot in the channel direction. During the experiment each pilot performed three successive runs on his ship, followed by a final run that involved a complete engine and rudder failure just at the entrance to the turn. The data from the experiment were then examined qualitatively and selected performance measures were subjected to statistical analyses. On this basis, observations and conclusions were made relating to the comparisons indicated previously.

38. McIlroy, William. 1983. Tug Usage with Impaired Maneuverability. CAORF Report No. 42-8114-02. Kings Point, NY: Computer Aided Operations Research Facility.

The investigations described in this report represent a second in a series of investigations planned at CAORF to study the effectiveness of tugs in restricted waterways and the variability in pilot operating procedures. One part of the previous study was concerned with the effectiveness of tugs in assisting an 80,000 DWT and a 250,000 DWT tanker following a complete failure with rudder amidships and a loss of engine power simultaneously, and just before entering a 45° turn. Because such a combined failure is extremely severe and has a low probability of occurring, the present study aimed at more realistic failure conditions on a rudder failure (amidships), or no failure at all could occur at any of the four locations prior to the turn, or four locations in the turn. In addition, the failure could be followed by a recovery in a realistic time period, or no recovery at all. Twelve subjects took part in the experiment; six had tugs available and six had no tugs. They performed a total of 12 runs apiece, and experienced engine and rudder failures with and without recovering and at various locations in an order consistent with the statistical experiment design.

The data from the experiment were examined qualitatively and selected performance measures were subjected statistical analyses. Based on these practically useful observations, conclusions were drawn from both the non-failure and failure runs regarding pilot procedures with helm, engine and tug power in relationship to the type and location of the failure.

39. McIlroy, William, and Gilbert Carpenter. 1983. Tug/Ship Control Strategies. CAORF Report No. 42-8212-01. Kings Point, NY: Computer Aided Operations Research Facility.

This report presents the results of five studies performed using the optimal tug-ship control strategy program at CAORF. They concern the application of tugs following a complete failure of a ship's engine and rudder prior to a 45° turn in a channel. In Study 1, the controls required for safety assisting an 80,000 DWT and a 250,000 DWT tanker are compared, using the minimum deviation off-track as the performance index and the tug pull as the single control. The magnitude of the pull remains constant at an assigned value.

In Study 2, the same situation is treated. However, two controls are included -- both the pull angle and the pull magnitude -- and in addition, the performance index is modified to include both the deviation off track and the deviation of speed from a desired value.

In Studies 3, 4, and 5, actual samples are selected from previous tug-ship simulation experiments performed at CAORF dealing with impaired maneuverability. These include failures on both ships. The optimization process considers only deviation off-track errors. The predicted optimal control procedures are then compared with those actually employed by the pilots during the simulation experiments.

40. Miller, E.R., and R.A. Barr. 1984. Effects of Alternate Channel

Configurations on Navigation in the Upper Mississippi River. Report No. CG-D-16-84. Washington, D.C.: U.S. Department of Transportation, U.S. Coast Guard.

This report summarizes results of a study of Upper Mississippi River tow maneuverability and maneuvering performance. Detailed qualitative and quantitative results obtained from simulations carried out by two experienced pilots for a selected 4.5 mile stretch of the river below Wabasha, Minnesota are presented and analyzed. Based on evaluations of the simulator by a total of four pilots, it was concluded that the simulator accurately modeled tow behavior. The analysis was directed toward determining the possible effects of channel geometry (minimum width and depth) on operational efficiency and safety. Qualitative and quantitative results both indicated a significant effect of channel width but only a small effect of channel depth.

41. Miller, Eugene R., Jr. 1979. Towboat Maneuvering Simulator Volume III - Theoretical Description. Technical Report No. 7909-1 Volume III. Washington, DC: U.S. Department of Transportation, U.S. Coast Guard.

The towboat maneuvering simulator is based on the integration in time of the differential equations which describe the motions of the towboat and barge string in three degrees of freedom, i.e., yaw, sway and surge. The theoretical background for these equations are presented in Reference 1, "The Prediction of River Tow Maneuvering Performance," U.S. Coast Guard Report No. CG-D-32-78. This reference presents the basic equations and a complete set of hydrodynamic coefficients for a representative towboat and barge train. These coefficients were obtained by model tests.

This section of the simulator documentation provides a description of the basic equations of motion included in the simulator and the

relationships used to determine external forces and moments due to bow thruster and wind. These equations are completely general in nature and could be used, with the proper hydrodynamic coefficients, to describe the maneuvering of vessels other than towboats.

42. Miller, William C., Jack C. Schryver, Jane Conway, and Samuel McGee.

1985. An Overview of the Hampton Roads Unification Project -- Final Phases. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development, pp. B2-1 -- B2-19. Kings Point, NY: National Maritime Research Center.

The Hampton Roads simulation study being conducted at CAORF was designed to assist the Norfolk District of the U.S. Army Corps of Engineers in determining initial dredging requirements to deepen the waterways from 45 feet to 55 feet. Hampton Roads is a major coal exporting port, but due to the 45-foot draft restrictions, many vessels are forced to leave partially laden. The CAORF study was designed to assist the Corps in determining the optimum channel designs which will allow safe vessel transits while minimizing dredging costs. The data developed by CAORF and the recommendations of the CAORF research staff will be used by the Norfolk District in accordance with current design criteria to design a comprehensive navigation system which would be acceptable to the U.S. Coast Guard and port users.

To conduct this study, much of the Hampton Roads area was modelled as part of a simulator data base. Two ships were developed for the program.



The first vessel (150,000 DWT coal collier), represents the largest vessels currently calling on the harbor. The second model (225,000 DWT coal collier) is a proposed wide beam vessel. The areas investigated were Norfolk Coal Terminals and Norfolk Harbor Reach Channel, Newport News Channel (present design and with a proposed bridge-tunnel), Entrance Reach and Thimble Shoal Channel, Anchorage Z, and Atlantic Ocean Sea Lane.

The project is not complete at this time. The dimension requirements have been estimated for all but Newport News with a bridge tunnel and the Atlantic Ocean Sea Lane. Berthing and unberthing requirements for the coal terminal at Norfolk have been assessed. Norfolk Harbor Reach Channel's deep-cut lane width has been estimated to be 650 feet. A flared entrance to the existing Newport News Channel was recommended with few proposed modifications to the channel itself. Dimension requirements for Entrance Reach and Thimble Shoal Channel have also been estimated. The evaluation of Anchorage Z indicated that both of the proposed spacing designs met clearance requirements but fail berthing energy requirements.

43. Miller, William C., Anita D. D'Amico, and Jack C. Schryver. 1982.

Simulation Evaluation of Proposed Port Arun LNG Terminal Expansion.

CAORF Report No. 75-7808-01. Kings Point, NY: National Maritime Research Center.

This document reports the results of research conducted at the Computer Aided Operations Research Facility (CAORF) simulation during the

summer of 1982 for Perusahaan Oertanbangan Minyak Dan Gas Bumi Negara (PERTAMINA). The primary purpose of this research was to evaluate whether a proposed second LNG vessel berth at Port Arun could be located 540 meters across from an already existing berth without presenting undue risks during docking and undocking operations. Three secondary purposes of the research were: to determine the maximum wind velocities under which undocking could safely occur from either berth; to determine the feasibility of nighttime operations; and to determine the amount of time required to evacuate both berths under an emergency situation. From one to eight pilots were run under 19 experimental scenarios. These scenarios varied: operation (docking, undocking); location of berth (north, south); wind direction (south-west, northeast) wind velocity (10 to 50 knots); and lighting (day,night). The eight primary scenarios in which all eight subjects participated in consisted of docking and undocking operations for both berths with wind speeds up to 20 knots from either northeast or southwest directions. Results indicate that the proposed 540 meter distance between berths appears adequate for docking and undocking under winds of 20 knots or less. Additional data show that undocking under 30 knot wind conditions is also feasible as well.

44. O'Hara, John M. 1982. An Investigation of the Feasibility of Piloting Large Ships Through the Chickasaw-Creek Channel: A CAORF Simulation. Prepared for Mobile-Chickasaw Port Facility, Inc. and U.S. Army Corps of Engineers, Mobile District. Kings Point, NY: National Maritime Research Center.

This study utilized the CAORF simulator to examine the feasibility of piloting a 65,000 DWT oil tanker through the Chickasaw Creek Channel. Two specific problem areas, identified by local officials, were passage through a swing type railroad bridge providing limited clearance and negotiation of a sharp turn at the northern end of the creek. The CAORF model of the channel included several modifications of existing facilities including placement of a dolphin arrangement located near the railroad bridge and a widening of the sharp turn. Two local pilots made several passages through these problem areas under favorable environmental conditions. The principal data recorded was distance of the simulated ship from the railroad bridge and channel boundaries. Ten passages were made through the railroad bridge, five by each pilot. It was concluded from the results that bridge passage was feasible. Six passages were made through the sharp turn area, three by each pilot. It was concluded from the results that under the conditions simulated the sharp turn area of the channel was problematic. In addition to these findings, other data were also presented. Several recommendations were made including a sequential, stepwise implementation in the real world.

45. O'Hara, John M., Jane A. Conway, and Brian C. Gilcher, 1986. The Navigability of the Main Ship Channel in the Mobile Harbor Deepening Project by Deep-Draft Vessels: A CAORF Investigation. Technical Report No. CAORF 27-8333-02. Prepared for U.S. Army Corps of Engineers, Mobile District. King's Point, NY: Computer Aided Operations Research Facility.

This report describes an investigation performed for the Mobile District Corps of Engineers and the Alabama State Docks Department to determine the navigability of a proposed channel deepening plan for Mobile Harbor designed to accommodate deep-draft bulk carriers. The study was conducted at the U.S. Maritime Administration's Computer Aided Operations Research Facility (CAORF). Five scenarios were developed to examine the navigability of the proposed 400-foot wide, 55-foot deep Main Ship Channel by loaded 150,000 DWT coal carriers. Three scenarios represented an outbound transit through Upper, Middle, and Lower Segments of the channel under favorable conditions. These three segments were identified due to their potential hazards to navigation, such as course changes and areas where side channels intersected the main ship channel. The final two scenarios represented passages through the Middle and Lower Segments under an adverse thunderstorm condition to determine its influence on channel navigability. An additional scenario was developed to provide familiarity to seven Mobile pilots participating in the study. Each pilot made one transit under each scenario condition. The results indicated that pilots were able to successfully navigate the collier through the majority of channel zones examined. The only problem areas were related to turns which required course changes in excess of ten degrees. It was recommended that these turns be widened to give pilots additional maneuvering area. Several other recommendations concerning the harbor design plan were also made.

46. O'Hara, John M., and William Ficker. 1985. An Evaluation of a Modified Channel Design for the Mobile Harbor Deepening Project. Report No. CAORF 27-8333-04. Prepared for U.S. Army Corps of Engineers, Mobile District. King's Point, NY: Computer Aided Operations Research Facility.

This report describes the second study performed for the Mobile District of the U.S. Army Corps of Engineers and the Alabama State Docks Department to determine the navigability of a proposed channel deepening plan for Mobile Harbor designed to accommodate deep-draft bulk carriers. The study was conducted at the U.S. Maritime Administration's Computer Aided Operations Research Facility (CAORF). CAORF contains a real-time, full-mission shiphandling simulator. The first study (CAORF 27-8333-02) generally supported the navigability of a 400-foot wide and 55-foot deep ship channel by loaded 150,000 DWT bulk carriers. Several problem areas were noted. This second study evaluated the effect on navigability of several proposed modifications to the first channel design. These modifications included widening of problem areas identified in the first study, inclusion of a passing zone, narrowing of straight channel segments of 300 feet, and improvement to aids to navigation. Scenarios were developed to simulate outbound transits through the modified design under favorable and adverse environmental conditions. Familiarity scenarios were also developed. Seven Mobile pilots participated in the study. The results generally indicated that the 300-foot wide channel and many of the

proposed modifications to the initial design were associated with navigation difficulties. Recommendations included support for the original 400-foot wide channel design and additional modifications.

47. O'Hara, John M., and J.C. Schryver. 1986. The Validation of Marine Simulation Research Studies. Paper presented, Eastern Simulation Conference.

The concept of validity is addressed from the perspective of simulation research methodology rather than the validation of the simulation models. The usefulness of simulation research is dependent as much upon the use of appropriate research methods, as on the fidelity of the models. The concept of research methodology validation is discussed along four dimensions: Construct Validity, Statistical Conclusion Validity, Internal Validity, and External Validity. These dimensions span the entire research process from the definition of variables to the construction of inferences for the generalization of study results.

48. O'Hara, John M. and William S. Brown. 1985. An Investigation of the Relative Safety of Alternative Navigation System Designs for the New Sunshine Skyway Bridge: A CAORF Simulation. Report No. CAORF 26-8232-04. Prepared for Florida Department of Transportation and U.S. Maritime Administration. King's Point, NY: National Maritime Research Center.

This report describes an investigation performed for the Florida State Department of Transportation (FDOT) to determine the relative safety afforded the new Sunshine Skyway Bridge by three alternative navigational system designs. A "navigation system design" was a specific configuration of channels, aids to navigation, and shipboard navigation aids in the vicinity of the bridge. The first design included a relocation and redesign of the new bridge when compared with the existing bridge. The second design included the availability of a precision electronic aid to aid pilots in determining their position. The third design included a redesign of the channel approach to the bridge which displaced a course change that was less than one nautical mile to almost three nautical miles from the bridge. A fourth design was also included in the study to serve as a baseline condition against which to compare the three alternatives. The design was modelled to include the existing Sunshine Skyway Bridge and the channel and aids to navigation configuration that existed in May 1980 when the SUMMIT VENTURE struck the bridge causing extensive damage to the bridge and the loss of 35 lives. Nine scenarios were developed to compare bridge safety of the four designs during the transit of a 160,000 DWT tanker. Safety was principally defined in terms of measures of vessels proximity to bridge structures. The transits were generally made during adverse conditions consisting of heavy fog or thunderstorms. A limited number of transits were made under favorable environmental conditions to aid in the establishment of baseline levels of performance. The transits were made by seven Tampa Bay pilots. The results indicated that vessel transit under thunderstorm conditions were less safe than transits under fog conditions. All three of the navigational system designs were found

to be safer than the design that existed in 1980. Of the three alternatives, the design which included the precision electronic navigation aid was found to provide greater bridge safety than the other two. The redesign of the channel approach was not found to provide additional safety beyond the relocation and redesign of the bridge alone. It was, therefore, recommended that the design alternative including the precision electronic aid be supported and the design including the channel redesign not be supported.

49. O'Hara, John M., and William S. Brown. 1986. An Evaluation of the Effectiveness of a Proposed Channel Design Modification for Navigation Risk Mitigation in Portsmouth Harbor. CAORF Report No. 26-8410-02. Prepared for U.S. Army Corps of Engineers, New England Division. Kings Point, NY: Computer Aided Operations Research Facility.

A study was conducted to evaluate the degree to which vessel and waterway safety can be expected to increase as a result of proposed channel modifications in the Piscataqua River in Portsmouth Harbor, New Hampshire. The study was undertaken for the U.S. Army Corps of Engineers - New Hampshire District and employed the shiphandling simulator at MARAD's Computer Aided Operations Research Facility (CAORF). The modifications were intended to facilitate passage of large vessels through difficult channel bends and to allow room for emergency maneuvers. Portsmouth Harbor pilots conned a tanker through simulations of both existing and proposed waterway under both unrestricted and restricted visibility conditions. Emergency maneuvers were also undertaken.



Variables of interest included vessel proximity to channel banks and bridge piers, indicators of vessel controllability, and measures of pilot workload. Performance was analyzed separately for a number of areas adjacent to the proposed improvements. In general, it was found that the proposed channel was associated with greater safety (greater clearances from banks and bridge piers) and operational ease (greater vessel controllability) as compared with the existing channel.

50. Perdok, J., and Th. Elzinga. 1984. The Application of Micro Simulators in Port Design and Ship Handling Training Courses. In Proceedings of the Third International Symposium on Maritime Simulation (MARSIM), pp. 215-225. Rotterdam, The Netherlands: Maritime Research Institute Netherlands.

MARIN initiated a research program to investigate the application of micro-simulators in port design and ship handling training courses. An experiment to investigate the possible application of micro-simulators in research relating to the design of approach channels is the subject of this paper. The two most important factors, investigated in the experiment, were simulator type (point light source simulator and micro-simulator) and view (panoramic and bird's-eye-view). The results indicate that large differences exist in the performance of the man-ship-system as a function of view, whereas only minor differences are found as a function of simulator type.

51. Petrie, George L. 1978. Simulation of Bridge Collision Incidents Involving Inland Waterway Tows. Report No. CG-D-48-78. Washington, DC: U.S. Department of Transportation, U.S. Coast Guard.

A mathematical model has been formulated to simulate the motion of a river barge flotilla maneuvering in an inland waterway. The mathematical model includes the inertial and hydrodynamic forces due to the motion of the flotilla through the water, as well as applied forces due to rudder and propeller action, wind and current effects. The layout of virtually any river channel boundaries, along with arbitrary wind and current speed and direction (including cross currents, non-uniform currents and eddys) can be easily described in the model coordinate system. In the present formulation, bank suction and shallow water effects are neglected.

The mathematical model has been implemented in a FORTRAN computer program. The program is written to run in a "conversational" mode, periodically displaying the present status of the simulation to the user, and prompting for input of updated rudder and speed commands. The program has been structured to permit different tow characteristics and steering strategies to be evaluated with a minimum of difficulty. A sample program input deck and output listing are shown.

This volume provides a description of the theoretical basis of the model.

52. Puglisi, Joseph J. 1985. CAORF's Cooperative Role in the Application of Simulation to Optimizing Channel Design and Maintenance. In Proceedings, Sixth CAORF Symposium, Harbor and Waterway Development, pp. 1-35. Kings Point, NY: National Maritime Research Center.

The use of marine simulation in port and waterway development and the cooperative endeavors undertaken in the last 15 years by CAORF and the marine industry in the use of CAORF facilities as a national transportation resource are described.

53. Riek, J., S. Tenenbaum, and W. McIlroy. 1987. Investigation into Safety of Passage of Large Tankers in the Puget Sound Area. CAORF Report No. 41-7703-01. Prepared for U.S. Coast Guard, Washington, D.C. Kings Point, NY: National Maritime Research Center.

A study was conducted at the Computer Aided Operations Research Facility (CAORF) to investigate the safety of passage of tankers through the Puget Sound area under maximum credible adverse environmental conditions. The study was conducted in two phases: off-line using a computer program to simulate the performance of various size tankers; and on-line, utilizing the CAORF simulator with human test subjects. In each phase, there were two types of runs: track keeping runs, and failed equipment runs. The track keeping results indicated that all ships were able to navigate safely under the extreme environmental conditions provided they maintained sufficient speed. The failed equipment runs indicated that tug support of ships was required to avoid grounding after suffering steering/propulsion failures.

54. Schryver, Jack C. 1983. The Application of CAORF as a New Technology for the Determination of Channel Navigability and Width Dimension Requirements: Newport News Channel. CAORF Report No. 27-8205-02. Prepared for U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: Computer Aided Operations Research Facility.

This report describes the second phase of a study performed for the U.S. Army Corps of Engineers (COE), Norfolk District, which utilized the resources of the Computer Aided Operations Research Facility (CAORF). The Norfolk Harbor Deepening Project specifies a project depth of 55 feet for the major access channels in order to promote the use of large coal carriers at Norfolk and Newport News, Virginia.

Shiphandling data was collected for simulated unberthing and outbound channel transits in Norfolk Harbor Reach and the channel to Newport News. Active members of the Virginia Pilot Association and Chessie System piloted two large deep-draft design vessels under variable environmental conditions through a 650 foot wide outbound lane in Norfolk Harbor Reach. Docking masters simulated unberthing maneuvers from Pier 14 at Newport News with the assistance of four 4,500 hsp. tug boats and pivoted the vessel for channel entry. Pilots then brought the vessel into the channel and continued the outbound transit into Entrance Reach.

Statistical analyses were employed to determine the navigability of the 650 foot wide lane in Norfolk Harbor Reach and Newport News Channel under variable conditions. Predictive envelopes of operation were constructed for the entrance and bend in the channel to Newport News.

Recommendations were made to assist the COE in finalizing channel design plans for initial phase construction.

55. Schryver, Jack C. 1985. A Simulator Evaluation of the Operational Requirements for a Fixed Mooring Facility for Deep Draft Vessels. Prepared for U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: Computer Aided Operations Research Facility.

This report describes the fourth phase of the Hampton Road research program performed for the U.S. Army Corps of Engineers (USACE) Norfolk District, which utilized the resources of the Computer Aided Operations research Facility (CAORF). The USACE has proposed that a Fixed Mooring Facility be constructed in the inner harbor at Hampton Roads in order to provide deep draft anchorage for up to six vessels. Simulated berthing and unberthing exercises were conducted at the center-north berth of the proposed facility. Fourteen experienced local docking masters controlled a ballasted 150,000 DWT coal carrier with the aid of tugs under variable wind velocity. The two facility designs which were evaluated differed only in separation distance between adjacent moorings: 750 feet or 1000 feet. Berthing energies and clearances to the moored vessel in the opposite berth resulting from the simulated exercises were calculated and employed as the main valuation criteria. Resulting clearances appeared to be adequate for both wind speeds, especially at the 1000-foot separation facility design. Berthings energies were found to be from 10 to 20 times greater under wind-hindered as compared to wind-assisted berthing.

56. Schryver, Jack C. 1986. A CAORF Investigation of the Navigability and Width Dimension Requirements of Thimble Shoal Channel and Adjacent Areas. CAORF Report No. 27-8220-02. Prepared for U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: Computer Aided Operations Research Facility.

This report describes the third phase of the Hampton Roads research program performed for the U.S. Army Corps of Engineers (USACE) - Norfolk District, which utilized the resources of the Computer Aided Operations Research Facility (CAORF). The purpose of the study was to evaluate the navigability of deep-cut lanes of variable width in Thimble Shoal Channel and Entrance Reach. An asymmetrical channel design will allow the outbound lane to be dredged to a depth of 55 feet, whereas the remainder of the channel can be maintained at an initial depth of 45 feet. Simulated outbound transits of the project elements were conducted by 27 experienced local pilots under variable current velocity and visibility. The design vessels were a 150,000 DWT coal carrier and a proposed shallow draft design 225,000 DWT coal carrier. Numerous penetrations of the northern lane boundary in Entrance Reach were recorded under all environmental conditions for both the 500-foot wide lanes. In the worst-credible current velocity conditions, approximately one half of the trials resulted in a penetration of either the northern or southern boundary. In the presence of average current velocity, although there were a few boundary penetrations of the 500-foot wide lane, there were no instances of bank sidewall contact in the 650-foot wide lane.

57. Smith, M. W., K. L. Marino, and J. Multer. 1985. Short Range Aids to Navigation Systems Design Manual for Restricted Waterways. Report No. CG-D-18-85. Prepared for U.S. Department of Transportation, U.S. Coast Guard, Washington, DC. North Stonington, CT: Eclectech Associates Division of Ship Analytics.

This manual is intended to supplement the system design guidelines presented in Chapter 4 of the Aids to Navigation Manual - Administration (COMDTINST M16550.7). It provides procedures for designing or evaluating systems of aids in restricted waterways navigated by deep draft vessels. As such, it is an appropriate tool for use by the District Aids to Navigation Branch when conducting regularly scheduled waterways evaluations under the Waterways Analysis and Management System (WAMS) (COMDTINST M16500.11). Besides its structured approach to system design and evaluation, the manual provides a measure of quality for candidate aid configurations. This measure of quality is presented as an assessment of risk, providing the District or Headquarters analyst with an objective, quantifiable measure of effectiveness to support operational and budgetary decisions.

58. Stewart, J. Phillip, Larry L. Daggett, and Robert F. Athow. 1985. Impact of Proposed Runway Extension at Little Rock Municipal Airport on Water Surface Elevations and Navigation Conditions in Arkansas River. Department of the Army Miscellaneous Paper No. HL-85-3. Vicksburg, MS: Waterways Experiment Station, Corps of Engineers.

A 2-D numerical hydrodynamic model was coupled with a 2-D numerical sediment transport model to predict the impact of a proposed runway extension on water-surface elevations in the Arkansas River at Little Rock, Arkansas. The hydrodynamic results were also used as input data to a ship simulator to predict the impact of the proposed runway on navigation characteristics.

The proposed runway will have a noticeable effect on the water-surface profile in the study reach. However, the increased head loss will not violate the 0.5 ft.-maximum swellhead criterion. Velocities at and downstream of the construction will increase approximately 1 fps, or at least 10 percent. While there are some effects on navigation observed due to the proposed project, there does not appear to be any significant increase in navigation difficulty due to the runway extension.

59. Tenenbaum, Sol. 1979. Application of Fast-time Simulation to Waterways Analysis. In Proceedings, Third Annual CAORF Symposium, Maritime Simulation Research, pp. 22-1-22-19. Kings Point, NY: National Maritime Research Center.

During the past two years, a number of waterway investigations have been conducted at CAORF, each with a different objective and each unique in its application of online (CAORF) and off-line (fast-time) simulation techniques. Two of these investigations are discussed in this paper. The philosophy behind fast-time simulation as applied to waterway investigations is discussed herein. Directions for future research and development to improve the fast-time simulations are also indicated.



60. U.S. Army Corps of Engineers, 1984. General Design Memorandum Mobile Harbor Deepening. Design Memorandum No.1. Appendix E Simulation Models, Mobile, Alabama.

Appendix E contains the reports prepared documenting the methodologies, techniques, analyses, and findings of three simulation models used in evaluating plans for deepening Mobile Harbor. These models were used for determining ship navigability of a narrow channel; delays expected from various channel widths; and impacts of channel widening, turning basin, and anchorage area. The simulation models are presented in three sections.

Section I is "The Navigability of the Main Ship Channel in the Mobile Harbor Deepening Project by Deep-Draft Vessels - A CAORF Investigation", by Dr. John M. O'Hara of the Computer Aided Operations Research Facility, National Maritime Research Center, Kings Point, New York. This report describes an investigation performed for the Mobile District Corps of Engineers and the Alabama State Docks Department to determine the navigability of a proposed channel deepening plan for Mobile Harbor designed to accommodate deep-draft bulk carriers. Five scenarios were developed to examine the navigability of the proposed 400-foot wide, 55-foot deep Main Ship Channel by loaded 150,000 DWT coal carriers. The results indicated that pilots were able to successfully navigate the collier through the majority of channel zones examined. The only problem areas were related to turns which required course changes in excess of ten degrees. It was recommended that these turns be widened to give pilots additional maneuvering area.

Section II is the "Mobile Harbor/Channel Vessel Traffic Simulation", by Dr. M. J. Niccolai of the University of South Alabama, Mobile, Alabama. A simulation model of the Mobile Channel and Harbor facility was developed using the SLAM II language. This model incorporated the logic and code necessary to simulate the action of two way traffic within the channel limits (length and width). In addition to sequencing vessel traffic from both directions (up and down channel), the model was used to delay vessels which would be involved in non-compatible, due to beam restrictions, head-on passing situations. Finally, the logic required to simulate the addition of a safe, head-on passing lane was included to measure the effect of the passing lane on the overall system waiting cost.

Section III is the Unpublished Waterways Experiment study on the impacts of navigation improvements in upper Mobile Harbor by Mr. Carl Huval, Waterways Experiment Station, Vicksburg, Mississippi. This report presents the results of a navigation study conducted on the Waterways Experiment Station ship/tow simulator. The purpose of the study was to investigate navigation improvements due to channel widening in the upper Bay area. The impact of the proposed anchorage area and turning basin was also investigated.

As a part of the investigation a reconnaissance trip aboard a typical bulk carrier was conducted to observe pilot maneuvers and to record the inbound ship transit with video tape equipment and still photographs. Special tests were conducted on the Mobile Bay scale model to record current patterns in the upper Bay study region. The study area navigation

channels were schematized on the simulator using available navigation charts and topographic maps, and District furnished hydrographic survey data. Ebb tide current data from the physical model were used to give realistic inbound test conditions on the simulator. The simulator visual scene was created using the data recorded during the inbound ship transit and maps and charts.

The study showed that careful pilot control was required to maneuver the simulated ship in the 400-foot wide channel in the upper Bay reach. Anticipating the ship response at the Arlington Channel and the docked ship was necessary to prevent ship grounding or collision. The 650-foot widened channel plus the anchorage area and the turning basin increase the safety margin in the upper Bay reach by greatly decreasing the bank suction forces at Arlington Channel and the docked ship. The proposed project will provide greatly improved navigation conditions in the upper Bay.

61. U.S. Department of Commerce. 1978. Analysis of LNG Carrier Docking Performed on CAORF Ship Simulator. CAORF Report No. 41-7702-01. Kings Point, NY: National Maritime Research Center.

This report documents the study of wind effects on LNG carrier docking performance at MarAd's Computer Aided Operations Research Facility. Experienced ship masters docked a simulated LNG carrier with various wind speeds and directions. Half of them used a true motion vector docking display as an aid. The best performances were by the masters who used the docking display. High winds blowing onto the dock caused hard contacts

with the dock (exceeding 0.2 knot). It was determined that the docking should probably not be attempted in the presence of high winds (+25 knots) blowing perpendicular to the dock.

62. U.S. Maritime Administration. Aids to Navigation Systems and Meeting Traffic. CAORF Project no. 8403. Kings Point, NY: National Maritime Research Center.
63. U.S. Maritime Administration. The Development of Tug and Barge Models for a Simulator Training Research Program. CAORF Project no. 8404. Kings Point, NY: National Maritime Research Center.
64. U.S. Maritime Administration. Exxon Port Study. CAORF Report No. 24-8119-01. Kings Point, NY: National Maritime Research Center.
65. U.S. Maritime Administration. Guidelines for the Utilization of Shiphandling and Hydraulic Simulation in the Waterway Design Process. CAORF Project no. 8609. Kings Point, NY: National Maritime Research Center.
66. U.S. Maritime Administration. 1983. Literature Survey of Moorings for Anchorage Z. Prepared for U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: National Maritime Research Center.

This report provides a broad overview of a study of the factors to be considered in design and construction of offshore mooring structures, both

on marine simulator and in the real world, in the Anchorage Z area of Newport News. This overview is based primarily on a literature search of various information sources in subject areas including berthing, berthing impact forces, dolphins, fenders, mooring, mooring systems, marine structures design, etc. The literature search was conducted to collect and utilize information on previously built offshore mooring/terminal structures toward recommending simulation design and providing the COE with sources of information concerning factors that must be considered in the real world design of such structures. Of course, the overall planning and design of an offshore mooring terminal requires the involvement of many experts studying pertinent data and providing recommendations based on their expertise. These experts include port designers, engineers, mariners, economists, legal and regulatory personnel, environmentalists, geologists, etc. The data studied and utilized include transportation flow patterns, economic conditions and trends, navigation conditions, soil and bathymetric conditions, hydrographic and meteorological conditions, ship design parameters, mooring line forces, etc., as well as results of work done previously in construction of similar designs and simulation of various operational conditions to study proposed designs. This report focuses in on possible designs for offshore mooring structures in Anchorage Z based on physical, operational and environmental constraints of the area and proposes a design for simulation as part of the work effort performed for the Norfolk COE.

67. U.S. Maritime Administration. 1985. Norfolk Harbor and Channels Deepening Design Simulation Studies: Summary Report. Prepared for U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: Computer Aided Operations Research Facility.

The U.S. Army Corps of Engineers (USACE), Norfolk District, has proposed a construction plan designed to ready the major access channels at Hampton Roads for the full loading of deep-draft vessels at the earliest possible date. The objective of this construction plan is to allow the incremental construction of those project elements that will provide usable project elements. The phased construction plan will be based on a priority list of the major access channels according to their importance to deep-draft navigation.

Incremental deepening may be employed to uniformly deepen access channels across their entire width in discrete phases, thus allowing the large deep-draft vessels to progressively increase their load to full capacity.

The concept of incremental widening involves the initial deepening of the channel across only a fraction of the total width. Successive phased construction would extend the initial cut to the entire width. This strategy would create a deep-cut lane on one side of the channel which fully laden deep-draft vessels may use as a maneuvering lane during outbound passage. Inbound traffic would be confined to the shallow side of the channel when meeting vessels transiting the deep-cut lane.

The USACE - Norfolk District opted for state-of-the-art simulation methodology as a decision aid to channel deepening design and evaluation. Although traditional methods and judgement could not be replaced by shiphandling simulation methodology, it was necessary to augment

traditional methods through the quantification of the pilot's ability to control the design vessel in each project element under variable environmental and operating conditions.

The major advantage gained through the use of simulation methodology is the ability to develop an efficient, modern harbor design which does not compromise the safety of ships transiting the full-scale environment. The CAORF simulation program for Hampton Roads was designed to determine channel dimension and entrance requirements, terminal maneuvering area requirements, and the feasibility of an asymmetrical channel construction elements.

68. U.S. Maritime Administration. Simulation Capabilities needed for Harbor and Waterway Design Studies. CAORF Project no. 8507. Kings Point, NY: National Maritime Research Center.

69. Van Dyke, Peter. 1980. An Analysis of the Berwick Bay Bridge Passage. Report No. CG-D-68-81. Washington, DC: U.S. Department of Transportation, U.S. Coast Guard.

A towboat simulator analysis of the Atchafalaya River at Berwick, La., has been carried out. Autopilot and manned passages were made on the simulator with different tow characteristics, going both upriver and downriver, and with and without bow thruster assistance. Five different power levels were represented by different engine RPM values, and this combined with the two different tow lengths results in ten HP/L ratios for

analysis. In addition, a casualty analysis was made of an April 1, 1978 collision between a tow and the bridges over the river.

70. Vann, Ronald G., and Samuel E. McGee. 1986. Simulator Effectiveness for Deep Draft Navigation Project Design. Paper presented, Eastern Simulation Conferences.

The design of deep draft navigation projects requires the integration of a large number of variables in order to assure a safe and efficient navigation system. The use of full-scale, real-time vessel simulation provides an effective means to integrate several design variables and permits a statistically valid analysis of the respective designs.

71. Walden, David A., and Ronald K. Gress. 1981. A Survey of Coast Guard Simulator Development Research and Simulator Applications. In Proceedings of the Second International Conference on Marine Simulation (MARSIM), Volume I, pp B4-1 -- B4-20. Kings Point, NY: National Maritime Research Center.

The Coast Guard is actively involved in many phases of marine simulation. This paper provides a survey of a number of Coast Guard projects in the areas of simulator development and applications. In several cases these projects involve joint efforts with other organizations, including the Maritime Administration, the U.S. Army Corps of Engineers and private industry. The projects discussed include the development of mathematical maneuvering simulation equations incorporating the effects of wind, waves, shallow water, bank effects and current. A



program written to generate current speed and direction maps for complex waterway flow conditions in an arbitrary topography is described. The ability to simulate the special conditions of slow speed maneuvering, high drift angles and the use of flanking rudders associated with inland waterway push towboat operation is discussed. Past and future efforts aimed at the collection of coefficients required in the use of such simulation equations for a range of ship types, verification through full scale trials, model tests, and analytic studies are reviewed. Other work includes the development of sophisticated control/autopilot equations for use in fast time simulation work. Using a real time/fast time maneuvering simulator based on the above efforts, a number of applications to Coast Guard problems are briefly discussed including deepwater port operations and the investigation of special regulations for difficult passages during certain adverse environmental conditions.

72. Williams, K., D. Nieri, J. Schryver, and W. Miller. 1982. The Application of CAORF Simulation as a New Technology for the Determination of Dredging Requirements. CAORF Report No. 20-8104-02. Prepared for U.S. Department of Transportation, Maritime Administration, and U.S. Army Corps of Engineers, Norfolk District. Kings Point, NY: National Maritime Research Center.

This report describes the methodology and results of a study performed for the U.S. Army Corps of Engineers, Norfolk District, which utilized the resources of the Maritime Administration's Computer Aided Research Facility (CAORF). The Norfolk District COE is embarking on a long term

harbor improvement project for the Port of Hampton Roads, Virginia, which includes deepening ship channels to a depth of 55 feet in order to promote the use of larger vessels in the carriage of coal from terminals in Norfolk and Newport News, Virginia.

This CAORF program collected data under simulated ship operations in Norfolk Harbor, which included large collier shiphandling in a narrow outbound lane and maneuvering off of two coal piers. The programs principle objectives were twofold:

1. Supply data to determine the feasibility of and identify the minimum width for dredging of an outbound lane in the 1500 foot wide channel of Norfolk.
2. Supply data to determine the required dimensions and location of a dredged maneuvering basin for large colliers at a proposed site for a coal handling facility.

Using the ship maneuvering simulator at CAORF, 12 Virginia pilots handled deep-draft collier models of two sizes under realistic environmental conditions to perform the docking and outboard harbor transits. Statistical analyses were performed on a broad spectrum of performance measures. The results of the data analysis identify predictive envelopes of operation for the large vessels in the Norfolk waterways which can assist the COE in finalizing their channel design plans for the initial phase of the waterway improvement project.

73. Williams, K., J. Goldberg, and M. Gilder. 1982. Validation of the Effectiveness of Simulator Experience Vs. Real-World Operational Experience in the Port of Valdez. CAORF Report No. 50-7917-02. Kings Point, NY: Computer Aided Operations Research Facility.

This study was designed to examine the effectiveness of simulator exposure and real-world observational experience in the Port of Valdez, Alaska in the learning of ship handling skills. Masters were tested on a simulated pilotage through the Valdez Narrows at the Maritime Administration's Computer Aided Operations Research Facility (CAORF) at Kings Point, New York. Performance data, measured as track deviation and percentage of time out of a prescribed tolerance band indicated equivalent performance for those masters with simulator experience or real-world observational exposure and significantly poorer performance for those masters with neither simulator nor real-world Valdez experience.

74. Witt, Franz G. J. 1981. Analysis of Simulated Maneuvers. In Proceedings of the Second International Conference on Marine Simulation (MARSIM), Volume I, pp. A12-1 -- A12-17. Kings Point, NY: National Maritime Research Center.

This paper discusses statistical analysis of ship maneuvering simulation studies used in channel width and depth design. Experiments involved a 250,000 DWT VLCC.

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